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LOW LATITUDE ATMOSPHERIC X-RAYS OBSERVED BY HEAO-1.(U)

JUL 79 J G LUHMANN, H R RUGGE, J B BLAKE F04701-78-C-0079

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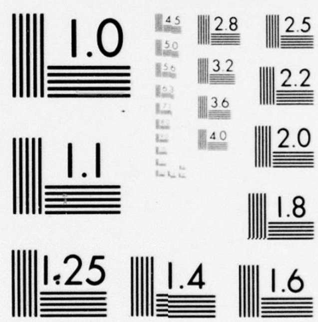

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Low-Latitude Atmospheric X-Rays Observed by HEAO-1

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16 July 1979

Interim Report

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Prepared for
SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
P.O. Box 92960, Worldway Postal Center
Los Angeles, Calif. 90009

This interim report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract No. F04701-78-C-0079 with the Space and Missile Systems Organization, Contracts Management Office, P.O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009. It was reviewed and approved for The Aerospace Corporation by G. A. Paulikas, Director, Space Sciences Laboratory. Gerhard E. Aichinger was the project officer for Mission-Oriented Investigation and Experimentation (MOIE) Programs.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SAMSO-TR-79-69	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) LOW LATITUDE ATMOSPHERIC X-RAYS OBSERVED BY HEAO-1		5. TYPE OF REPORT & PERIOD COVERED Interim rept.,
		6. PERFORMING ORG. REPORT NUMBER TR-0079(4960-05)-4
7. AUTHOR(s) Janet G. Luhmann, Hugo R. Rugge, J. Bernard Blake ~~and~~ Lee A. Christopher		8. CONTRACT OR GRANT NUMBER(s) F04701-78-C-0079
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Aerospace Corporation El Segundo, Calif. 90245		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 22p.
11. CONTROLLING OFFICE NAME AND ADDRESS Space and Missile Systems Organization Air Force Systems Command Los Angeles, Calif. 90009		12. REPORT DATE 16 July 1979
		13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Atmospheric Bremsstrahlung
Atmospheric X-Rays
Precipitating Particles
South Atlantic Anomaly X-Rays

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The low energy (0.15-3 keV) proportional counter detectors of the A-2 experiment on the x-ray astronomy satellite HEAO-1 have detected night-time atmospheric emissions at the limb of the earth. Three observations of this phenomenon occurred during the first two months of operation. On two occasions, fluxes greater than the diffuse galactic background were detected when the detectors scanned the limb in the vicinity of the magnetic conjugate point of the South Atlantic Anomaly. Enhanced emissions were → (over)

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19. KEY WORDS (Continued)

20. ABSTRACT (Continued)

also observed on a single scan of the atmosphere over northern Africa. The x-rays are presumed to result from bremsstrahlung generated by precipitating electrons. In the case of the emissions related to the Anomaly conjugate point, it is suggested that the electrons were secondaries backscattered from the atmosphere above the Anomaly during the intensified precipitation of radiation belt particles that occurs throughout a magnetic storm recovery period. These initial observations demonstrate that the earth's atmosphere can be a significant x-ray source at low latitudes as well as in the auroral zones, and hence that it may be practical to remotely monitor the global morphology of particle precipitation by satellite observations of terrestrial x-rays.

PREFACE

The authors wish to thank Stuart Bowyer and Philip Charles of the Space Sciences Laboratory, University of California, Berkeley for providing the LED data and other invaluable support for the purpose of the present analysis. We are also indebted to D. L. McKenzie of this laboratory for providing the computer code that describes the detector response to an incident x-ray spectrum. The A-2 experiment on HEAO-1 is a collaboration led by E. Boldt (GSFC) and G. Garmire (Caltech), which includes groups at GSFC, Caltech, Berkeley, and JPL.

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INTRODUCTION

The extent to which corpuscular sources contribute to atmospheric ionization at low and mid-latitudes is a question of current interest (e.g. see Potemra and Zmuda, 1970). Paulikas (1975) recently reviewed the status of subauroral particle precipitation, which is still a relatively unexplored area of magnetospheric physics.

Because energetic electrons precipitating into the atmosphere produce x-rays by the bremsstrahlung process (Berger and Seltzer, 1972; Luhmann, 1977), and also by the collisional excitation of the characteristic K_α lines of nitrogen, oxygen and argon (Kraushaar, 1974; Luhmann and Blake, 1977), x-rays provide a means of remotely monitoring electron precipitation on a global scale. Auroral (< 10 keV) x-rays have been observed from below by rocket borne instrumentation (Wilson et al., 1969) and more recently from above the emitting atmosphere by detectors carried on polar orbiting satellites (Mizera et al., 1978). The Lockheed group (Imhof et al., 1974) has carried out a satellite survey of energetic (> 50 keV) electron precipitation near the trapping boundary. These hard x-rays have also been detected for many years from balloons (Rosenberg et al., 1967; Chang, 1976, and references therein).

In fact, observations of x-rays generated by energetic particle precipitation at low latitudes were carried out soon after the discovery, in 1958, of the trapped radiation. Ghielmetti et al. (1964) measured enhanced atmospheric x-rays over the South Atlantic Anomaly ($\sim 315^{\circ}$) E longitude, $\sim 30^{\circ}$S. latitude) following a suggestion by Cladis and Dessler (1961) that x-ray emission should be generated by Van Allen belt electrons precipitating in this region of low geomagnetic field. However, only in recent years have technological advances made x-rays a potentially valuable means of assessing the global importance of particle precipitation in the formation of the ionosphere.

X-rays with energies below a few keV are a particularly sensitive indicator of precipitation. Because satellite-altitude bremsstrahlung spectra resemble power laws with negative exponents (cf. Seltzer and Berger, 1974), the greatest intensity is at low energies. Furthermore, the characteristic atmospheric K_α lines (N K_α at .396 keV, O K_α at .525 keV, and Ar K_α at 2.96 keV) add substantially to the flux below 3 keV (Luhmann and Blake, 1977).

The low energy detectors (LEDs) of the A-2 experiment on the x-ray astronomy satellite HEAO-1, which are sensitive to photons above $\sim$.15 keV (Rothschild et al, 1978), provided an unprecedented opportunity to search for electron precipitation outside of the auroral zone. A near equatorial orbit and fixed orientation make HEAO-1 an advantageous platform for viewing the atmosphere at latitudes $\leq 40^{\circ}$ which is scanned by the narrow field of view detectors as the satellite spins. In order to prevent detector degradation by local particle fluxes, the LEDs are not in operation when the satellite itself is in the South Atlantic Anomaly. In addition, relatively intense solar x-rays are scattered from the sunlit hemisphere (Rugge et al., 1978). Thus, the HEAO-1 detectors are primarily useful for observing precipitation that occurs outside of the South Atlantic region at night.

In this report several observations of .15-3 keV x-rays from the low and mid-latitude nighttime atmosphere are described. One observation indicates that the atmosphere over northern Africa sometimes emits x-rays. On two other occasions, emissions were detected by the HEAO-1 instruments as the detector field of view scanned across the limb of the dark earth near the magnetic conjugate point of the South Atlantic Anomaly. The x-ray spectra obtained from one of the latter "events" is used to infer the precipitating electron spectrum.

OBSERVATIONS

The A-2 experiment on HEAO-1 was described in detail by Rothschild et al. (1978). The two low energy proportional counter detectors (LEDs) have a spatial resolution of $1.5^{\circ} \times 3^{\circ}$ and $3^{\circ} \times 3^{\circ}$ and an energy range of .15 to 3. keV which is covered in 32 pulse height channels. HEAO-1 orbits the earth in a plane inclined $\sim 22.75^{\circ}$ from the equatorial plane, while its altitude ranges from ~ 425 to 450 km. The satellite spin axis points toward the sun. The LEDs look perpendicular to the spin axis. Since the spin period is approximately 1/3 of the ~ 1.5 hr orbital period, the LED fields of view scan the earth between latitudes of ± 40^{o} about three times per orbit.

Figure la illustrates the experimental configuration. Although the distribution of sub-auroral particle precipitation is still uncertain, the related x-ray emission is generally expected to occur in a belt-like volume within the satellite orbit where electrons in quasitrapped orbits dip into the atmosphere. The brightest region of the low latitude x-ray atmosphere is shown over the South Atlantic Magnetic Anomaly where the precipitation of quasitrapped particles reaches a maximum (Seward, 1973; Torr et al., 1975). Two zones of auroral x-ray emission have been added for completeness; however, they will normally be located below the horizon of the HEAO-1 detectors which is approximately 22^{o} from the subsatellite point. During periods of geomagnetic activity, this pattern will change with the distribution of precipitation.

Figure 1b illustrates the geometry of an observation of the atmospheric emission from a point P on the orbit. In general, the photon flux arriving at P from various lines of sight through the atmosphere will depend on both the satellite aspect angle α, which is measured with respect to the local horizontal as shown, and on the position of the emitting region relative to P. The attenuation of the photons along a particular line of sight, assuming no scattering occurs, will depend only on the aspect angle which determines the distribution of matter through which the photons must penetrate to reach the satellite. As a consequence of the optical path through the emitting atmosphere, an extended region of emission

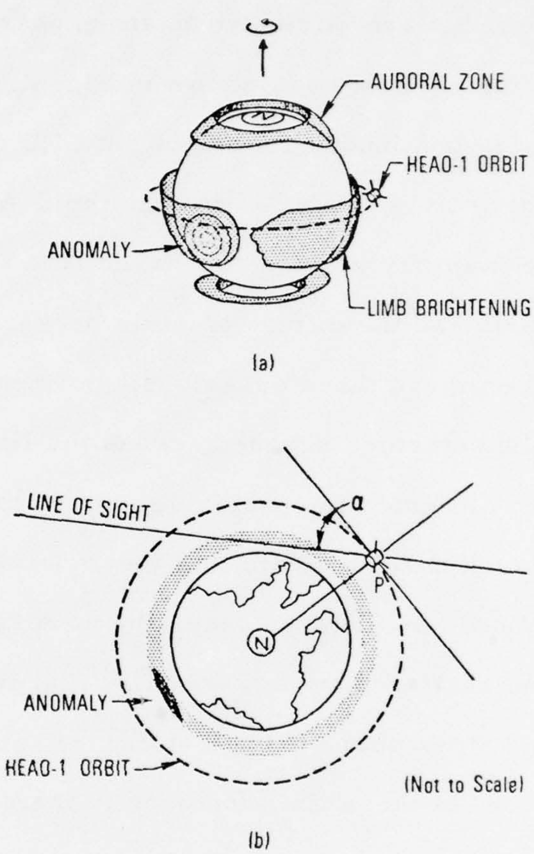

Figure 1 a) Schematic of the earth as an x-ray source, showing the location of the HEAO-1 orbit.

b) Geometry of the HEAO-1 observations of the atmosphere.

should be most visible to the satellite detectors when it is on the horizon, i. e. where a limb brightening geometry reinforces the intensity.

The observations that are attributed to atmospheric emission generated by precipitating particles are shown in Fig. 2. These data were selected from a nearly continuous record of the LED count rates obtained during the first ~600 orbits of HEAO-1 between mid-August and mid-September 1977. In the majority of cases observed, the transition at the limb between the dark earth and the diffuse galactic background emission was smooth. However, on these three occasions, distinct emission features were observed as the detectors scanned across the limb of the earth near local midnight. The absence of appreciable counts at the time when the detectors view the dark earth indicate that these data are free from local electron contamination. In all three cases the atmospheric flux is much less intense than the scattered solar x-ray flux that is observed during daylight scans of the atmosphere (Rugge et al., 1978).

The resemblance of these limb features to the response of the instrument to a point source suggest that the emission arises in a thin layer of the atmosphere. Geographical coordinates of the tangent point of the line of sight to the atmosphere at the time when the maximum flux was measured are given in Fig. 2 together with the altitude and the L value of the tangent point. The orbit 602 and 648 events on September 20 and 23, respectively, occurred near the conjugate point of the South Atlantic Anomaly. Similar emissions detected during orbit 241 were generated over northern Africa on August 27. The Dst index was low during the orbits when the atmospheric

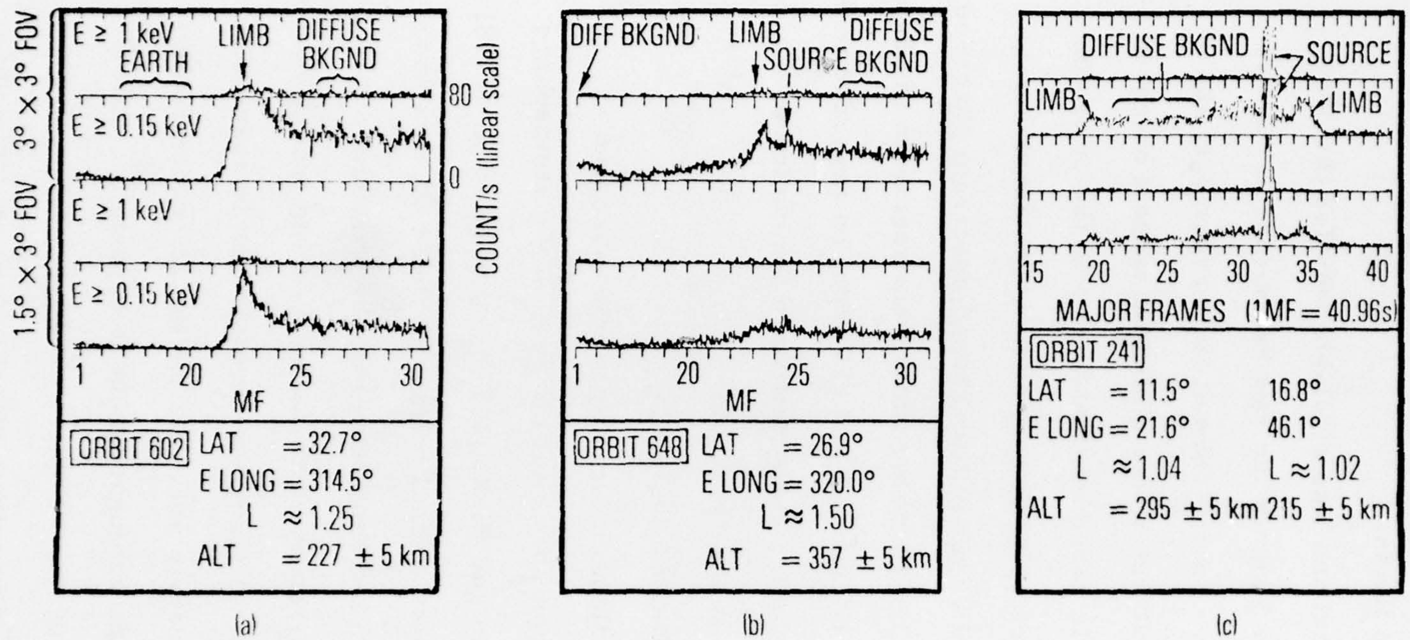

Figure 2 Count rate vs. time in two energy channels for sections of the three orbits where emission features were observed at the limb of the earth. Events (a) and (b) were detected on September 20 and 23, and event (c) occurred on August 27. Positions of the galactic background and celestial sources are indicated.

emissions were observed, indicating that the recovery from a magnetic storm was in progress at these times.

A statistically reliable spectrum was available only for the orbit 602 event (see Fig. 2). Figure 3 shows the raw "atmospheric" x-ray spectrum observed at the limb. During normal limb crossings, the diffuse galactic background is detected to a minimum tangent height of ~ 160 km. Because the galactic radiation contributes to the emission observed at the altitude of the atmospheric events, which reach maximum intensity above 200 km, the diffuse background spectrum observed near the limb has been subtracted from the limb event spectrum to obtain these data. The fluxes at energies $\gtrsim 1.2$ keV must be regarded with some skepticism since they appear to be sensitive to the choice of the background spectrum, itself a spatial variable.

INTERPRETATION

The relationship between the soft x-ray spectrum observed at satellite altitude and the electron spectrum incident on the atmosphere has been discussed by Luhmann and Blake (1977). Mizera et al. (1978) demonstrated the use of the calculational method of these authors in an analysis of correlated auroral electron and x-ray observations. In general, it was found that electron spectra can be inferred from observed x-ray spectra if a spectral form for the electrons is assumed.

Because the bulk of low latitude precipitation occurs in the South Atlantic, the precipitation at the conjugate point is expected to consist largely of secondaries and electrons backscattered from the anomaly region atmosphere. The energy spectrum of secondary electrons has

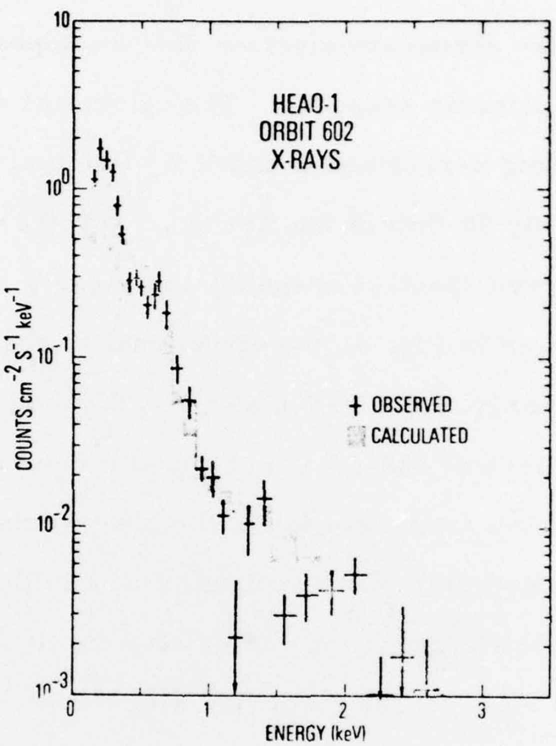

Figure 3 Raw spectrum of x-rays observed at the limb during orbit 602 compared with calculated results for incident electron spectra of the form $J(T) \propto T^{-\gamma}$ with $\gamma = 2.5$ to 3.0 where T is electron energy. The boundaries of the shaded band are determined by the limits on the value of γ.

the general form of a power law with a spectral index γ between 2.5 and 3.0 (Banks et al., 1974). Figure 3 shows how the x-ray spectra calculated for these secondary electron spectra appear when folded through the LED detector response. The calculated spectrum includes both bremsstrahlung x-rays and O and N K_{α} line emissions which comprise approximately 90-95% of the flux at .5 keV (see Luhmann and Blake, 1977). The observed spectral shape agrees closely with the calculations. Moreover, as shown in Fig. 4, the directional intensity profile for a nominal photon energy of 0.1 keV peaks at ~ 225 km, in excellent agreement with the altitude of 223 ± 5 km obtained for the maximum of the orbit 602 event. The normalization of the observed and calculated x-ray spectra yields an estimate of the incident electron flux. The inferred incident electron spectrum at the conjugate point of the Anomaly is given approximately by $J_o(T) \approx 300T^{-\gamma} cm^{-2} s^{-1} ster^{-1} keV^{-1}$, where T is the electron energy.

CONCLUSIONS

The agreement between theory and observation obtained above indicates that the nature of at least one of the observed limb events is reasonably well understood. More importantly, this analysis demonstrates that atmospheric x-rays from low and mid-latitude precipitating magnetospheric electrons can be observed from earth-orbiting satellites with existing detector technology, and that the x-rays can be used to obtain information about the precipitating electrons.

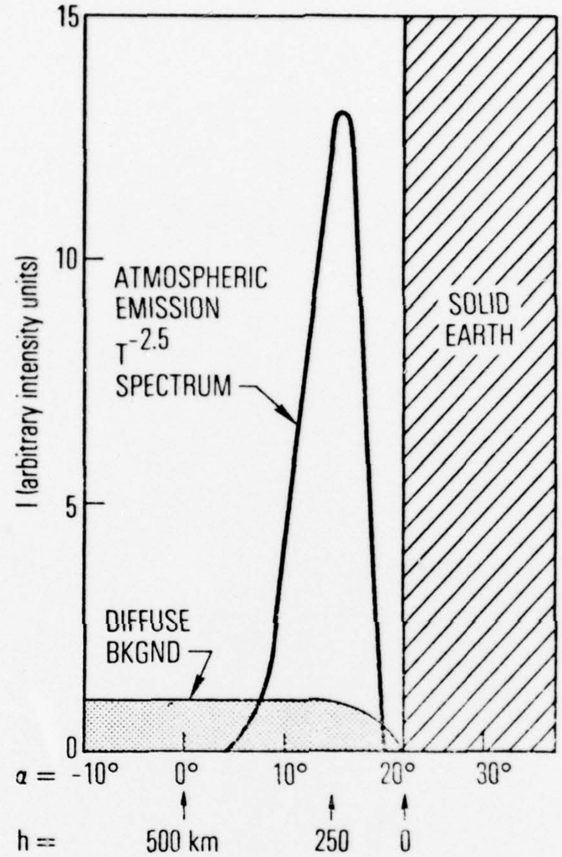

Figure 4 Altitude profile of .10 keV x-ray emissivity for an incident electron spectrum of the form $J(T) \propto T^{-2.5}$.

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